Power to the operators: Transdisciplinary co-design of XR applications in off-highway vehicle work domains

Manuel Kulzer, Tanja Brodbeck, and Michael Burmester

Hochschule der Medien, University of Applied Sciences, Stuttgart, Germany

Corresponding author: kulzer@hdm-stuttgart.de

Keywords: Transdisciplinarity, Co-Design, Participatory Design, Off-Highway Vehicles

Introduction

Transdisciplinarity is considered to be the key to facing societal and environmental challenges of the modern world and developing technology for complex sociotechnical systems (Jahn et al., 2012; Lawrence et al., 2022). Transdisciplinary research (TDR) is most commonly characterized by the involvement of both academic and non-academic actors in co-creative processes (Lawrence et al., 2022; Schneidewind et al., 2016), similar to the human-centred design (HCD) methodology (*ISO 9241-210, 2019*). HCD is widely established in human-computer interaction (HCI) research and XR application development (e. g., Krauß et al., 2021). However, in conventional HCD, the prioritization of requirements and the design and selection of solutions commonly remains reserved for the design and engineering teams (Nguyen Ngoc et al., 2022). TDR in contrast empowers non-academic actors from society through co-design (Lawrence et al., 2022), considering them experts for their domains (Sanders & Stappers, 2008) and elevating them to eye-level with the design team (Lawrence et al., 2022). While TDR is mainly found in education, urban planning, sustainability and environmental sciences (Lawless et al., 2024), it is less known in HCI or XR research. Co-design itself is well established in the HCI community under the term of participatory design, but does not seem to have gained much attention in XR application development. Thus, in this paper, we present a case study for transdisciplinary co-design of XR applications.

In the EU project THEIA^{XR}, XR technologies for the cabin of off-highway vehicles are being explored in the use cases of snow grooming, harbour logistics and construction. In these domains, the vehicle operators' working conditions make the use of handheld or head-worn devices impractical, which lead us to consider traditionally less-used applications of XR, such as thermal imaging and laser projections (Rooker et al., 2023). The transdisciplinary co-design procedure should ensure the co-creation of XR applications that are acceptable, easy and safe to use in the operators' sociotechnical environments. The main contributions of this paper are the methodical approach used to identify explicitly operator-approved XR application concepts suitable for the three off-highway vehicle use cases focused in the project, an overview of the resulting applications and implications of these results for future work.

Method

Based on the core principles of HCD, the design-based learning framework for co-creation labs (Real & Schmittinger, 2022), the conceptual model of an idealized TDR process (Lawrence et al., 2022) and scenario-based design (Rosson & Carroll, 2002), a transdisciplinary co-design approach was devised, see Figure 44.

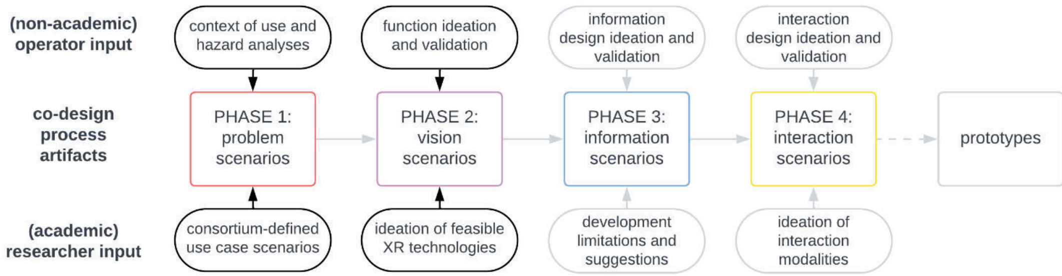

Figure 44. Structure of collaboration and artifacts in the transdisciplinary scenario-based design approach.

The approach comprises four phases. Phase 1 involved contextual inquiries (Holtzblatt & Beyer, 2017) and an adapted variant of the Critical Incident Technique (Flanagan, 1954) to learn about the context of use and potential hazards in the operators' work environment (see Figure 2). The results were incorporated into *problem scenarios* (Rosson & Carroll, 2002) as easily graspable artifacts for further use in the co-design process. In phase 2, we used the problem scenarios to collect viable XR technology suggestions from consortium partners and incorporated them into *vision scenarios* to envision future alternatives to the current status quo (Real & Schmittinger, 2022). The vision scenarios were discussed, expanded and validated with vehicle operators from all use cases in several co-design workshops (see Figure 45). Phase 3 and 4, which focus on information and interaction design (Rosson & Carroll, 2002), are still pending.

Figure 45: Left: Snow groomer exiting a garage during one of the phase 1 studies; Right: Picture from one of the phase 2 co-design workshops with vehicle operators in the snow-grooming use case.

Results

While discussing all findings of the context of use and hazard analyses and the qualitative results of the co-design workshops is going beyond the scope of this contribution, we present an overview of the XR applications identified and approved by vehicle operators over the course of the co-design process so far in Table 9. Operators in all use cases prefer to have their eyes on the work area as much as possible. This made the use of light bars around the cabin windscreen, conveying information through position, movement, size and colour of glowing areas from the corner of the eye, especially promising.

Similarly, laser projections can bring information directly to the areas that snow-groomer and excavator operators need to focus on and may reduce the need for shifting the attention to various displays. In the snow grooming use case, the greatest advantage was seen in visual aids for navigation even during heavy fog or snow storms. In the logistics use case, where remote control of reach stackers using a VR/MR environment is targeted, visualizations for the position of spreader twist locks in relation to the container corners would ease the efficient and precise placement and pick-up of containers. In the construction use case, visualizations (of any kind) of the locations and types – or even just the presence – of hidden underground structures (power lines, water pipes, etc.) would provide a great relief for excavator operators, who often find them accidentally in unexpected places.

Table 11. Summary of co-designed and operator-approved XR applications in the off-highway vehicle use cases

Use case	XR application
Snow grooming (snow groomer cabin)	• Ambient light bars around the windscreen with moving, glowing areas of different sizes and colours to indicate, e. g., vehicle health or AI-detected objects in vicinity • Highlighting target slope area in real time on onboard display based on digital slope model, possibly coupled with laser or light projections on the ground • Real-time laser projection of auxiliary lines indicating vehicle dimensions (for moving in tight spaces) and overlap with previously groomed lanes • Three-dimensional real-time visualization of current vehicle position and alignment on the slope on onboard screen • Display-based and/or laser projection of navigation indicators
Logistics (reach stacker remote control desk)	• Navigation indicators on top of (VR or monitor-based) camera view • Auxiliary projections on top of camera view facilitating container pick-up and placement, indicating correct spreader alignment with container and twist lock status • Visualization of container dimensions and projected turning areas on ground
Construction (excavator cabin)	• Recognition of excavation pit markings in the real world and automatic processing into the digital terrain model • Display-based visualization of the type and position of power lines and AI-detected objects in the work area on top of camera view • Laser projection of excavation pit boundaries, power lines etc., and optional auxiliary visualizations (e. g., minimum distance to excavation pit based on vehicle weight) • Ambient light bars around the windscreen with moving, glowing areas of different sizes and colours to indicate, e. g., AI-detected objects in the vicinity, distance of the bucket corners (left and right) to the target surface of the excavation pit

Conclusions

The results so far have shown that the transdisciplinary co-design approach serves to find viable and acceptable XR applications for off-highway vehicle work domains from operator perspective. Further research, e.g., on the perception of this approach from all involved roles, is needed to shed more light on its applicability in engineering-driven research and innovation projects. Regarding XR applications for off-highway vehicles, we see major potential in reducing the reliance on display-based information via, e. g., the use of ambient lights and audio, light and laser projections, or haptic feedback and force feedback. Lastly, we encourage the adoption of co-design in XR application development. Safety is a great concern for experienced off-highway vehicle operators – information overload or distractions by XR applications in the vehicle cabin may be an equally large safety risk as the lack of information itself.

Acknowledgements

Funded by the European Union under Grant Agreement No. 101092861. Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the granting authority can be held responsible for them.

References

Flanagan, J. C. (1954). The Critical Incident Technique. Psychological Bulletin, 51(July).

Holtzblatt, K., & Beyer, H. (2017). Contextual Design: Design for Life (2nd ed.). Morgan Kaufmann. http://educate.elsevier.com/book/details/9780128008942

ISO 9241-210:2019. (2019). https://www.iso.org/standard/77520.html

Jahn, T., Bergmann, M., & Keil, F. (2012). Transdisciplinarity: Between mainstreaming and marginalization. Ecological Economics, 79, 1–10. https://doi.org/10.1016/j.ecolecon.2012.04.017

Krauß, V., Boden, A., Oppermann, L., & Reiners, R. (2021). Current Practices, Challenges, and Design Implications for Collaborative AR/VR Application Development. Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, 1–15. https://doi.org/10.1145/3411764.3445335

Lawless, M. T., Tieu, M., Archibald, M. M., Pinero De Plaza, M. A., & Kitson, A. L. (2024). From Promise to Practice: How Health Researchers Understand and Promote Transdisciplinary Collaboration. Qualitative Health Research, 10497323241235882. https://doi.org/10.1177/10497323241235882

Lawrence, M. G., Williams, S., Nanz, P., & Renn, O. (2022). Characteristics, potentials, and challenges of transdisciplinary research. One Earth, 5(1), 44–61. https://doi.org/10.1016/j.oneear.2021.12.010

Nguyen Ngoc, H., Lasa, G., & Iriarte, I. (2022). Human-centred design in industry 4.0: Case study review and opportunities for future research. J. Intellig. Manuf. 33(1), 35–76. https://doi.org/10.1007/s10845-021-01796-x

Real, M., & Schmittinger, F. (2022). A Framework for Experimenting Co-creation in Real-Life Contexts. In A. Deserti, M. Real, & F. Schmittinger (Eds.), Co-creation for Responsible Research and Innovation: Experimenting with Design Methods and Tools (pp. 11–24). Springer International Publishing. https://doi.org/10.1007/978-3-030-78733-2_2

Rooker, M., Burmester, M., Fritz-Mayer, G., Arth, C., Lorenz, S., Waurich, V., Kulzer, M., Sergeeva, A., Helin, K., Pusenius, M., Geslot, B., Röck, D., & Yli-Paunu, P. (2023). Making the Invisible Visible for Off-Highway Machinery by Conveying Extended Reality Technologies. In K. Helin, F. Noël, & W. Schäfer (Eds.), Proc. 20th EuroXR Int. Conf. 2023 (pp. 38–47). VTT Technical Research Centre of Finland. https://doi.org/10.32040/2242-122X.2023.T422

Rosson, M. B., & Carroll, J. M. (2002). Scenario-Based Design. In A. Sears & J. Jacko (Eds.), The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications (3rd ed., pp. 1032–1050). CRC Press.

Sanders, E. B.-N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. CoDesign, 4(1), 5–18. https://doi.org/10.1080/15710880701875068

Schneidewind, U., Singer-Brodowski, M., Augenstein, K., & Stelzer, F. (2016). Pledge for a Transformative Science. Wuppertal Papers, 191_Wuppertal Paper.